Design and Analysis of Solar Agriculture Farm

A

Synopsis

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Introduction

In present scenario demand for continuous electricity supply is increasing day by day due to increase in population, increase in gadgets institutions and use of ICT facilities for e-Education etc. Broadly there are two sources of electricity generation: Renewable sources of energy and Non–Renewable Sources of energy. Non-Renewable sources of electricity generation consist of generation from Coal, Gas, Lignite, Diesel, Nuclear Energy and renewable sources of energy generation consist of Wind energy, Hydroelectric power plant, Solar Photovoltaic and Solar Thermal power plants, generation form ocean tides etc. As on today, the highest percentage of electricity generation comes from the non -renewable sources of energy that causes Climate Change, deterioration of air quality. Alarming air quality levels in many Indian cities and around the world have highlighted the deteriorating environment, and consequent the high-cost people are paying through the negative impact on their health. This all resulting in an immediate need to shift to cleaner and sustainable sources of energy generation mainly on Solar Energy due to its availability everywhere. The main constraint in the installation of Solar Power plant is the space requirement, availability of solar power and the un-certainty. It can be installed on both Rooftops and the ground. The rooftop Solar power plant are normally suitable to fulfil the energy requirement of a few buildings/campuses, but if solar power plant of higher kilowatts is needed and it is required to provide energy to grid also, then large area of land is required for the installation of power plant which will lead to a very high initial cost. The use of land only for the Solar power generation results in the wastage of precious land. Therefore, one possible solution of this problem would be use of agricultural land and the design of solar power plant in such way that the agricultural crops can also be grown in the same space where solar plants are installed. In this approach farmers will also be having an additional income from the electricity generation in case of the crop is affected due to some reason. This research will focus on the feasibility and performance of installing solar power plants on agricultural land. Analysis will be done to implement this concept in a most efficient manner to yield maximum benefits from both agriculture and the solar power generation.

Literature Review

Due to increase in population, there is a continuous demand for agricultural products. Newer techniques are being adopted to grow more food and variety of agricultural products in all seasons. Even efforts are being made to grow products of different climatic zones in a specific climate. Use of greenhouses for agriculture purpose is now increasing day by day. Studies shows that greenhouses have brought multi-fold growth in the income of the farmers. All these efforts require electrical energy to feed water, provide desired climate and operate different sensors for data collection and monitoring. It is normally not possible to extend the grid to these remote agricultural fields. Other sources of providing this energy may not be efficient and environment friendly. The only solution left is use of solar energy which is available in abundance in an open agricultural field. The greenhouses require electrical energy for proper functioning and use of solar energy can help build solar greenhouses in areas far away from the city/grid. Other applications of solar energy include irrigation, drying of agricultural produce, maintaining a cold chain and ventilation niches [1]. In order to meet global energy demands with clean renewable energy such as with solar photovoltaic (PV) systems, large surface areas are needed because of the relatively diffuse nature of solar energy. Much of this demand can be matched with aggressive building integrated PV and rooftop PV, but the remainder can be met with land-based PV farms. Using large tracts of land for solar farms will increase competition for land resources as food production demand and energy demand are both growing and competing for the limited land resources. This land competition becomes particularly acute in densely populated regions, mountainous areas, and small inhabited islands and is further fuelled by the increasing population by 1.15% per year [2-4]. These coupled land challenges can be ameliorated using the concept of Agri-Voltaics or developing the same area of land for both solar PV power generation as well as for doing agriculture [5]. There has been significant progress in solar photovoltaic (PV) technology to utilize the vast, clean and sustainable source of energy to satisfy energy demands [6, 7]. The IEA predicts approximately 6000TWh of PV power will be generated in 2050 to supply society's needs, which would be around 16% of the total energy generated [8]. To meet that predication and provide the concomitant greater portion of total global demand with PV, large surface areas are needed because of the relatively diffuse nature of solar energy. Theoretical and experimental work on agrivoltaics

analyses that the potential crop yields and solar power output is a function of the received solar radiation. For fixed tilt agrivoltaic farms, the optimal tilt angle of the PV is normally determined with an objective of maximizing solar power output and the pitch is determined by the spacing requirements of a given type of crop harvesting. As the PV create some shading on the crops planted between the rows, the sensitivity of the crop yield with respect to the shading effect is examined. The PV power output and crop yields are compared against that of an optimized PV power station and crop yields of conventional large-scale monocrop farms. A sensitivity analysis is performed based on the review of agrivoltaic research using the potential economic value of agrivoltaic farms to determine viability and for guiding future dual use farms. To combine food and energy production on the same piece of land is known as agrivoltaics. Although agrivoltaics have been theorized in the early 1980s using the space between PV rows for crops. The first detailed agrivoltaic farm experiments were only recently performed in Montpellier, France in 2013. This system consisted of tilt mounted PV modules which were 0.8mwide, mounted at a height of 4m and tilted at an angle of 25°. Lettuce crops were grown beneath these tilts and the lettuce yields and the behaviour of the lettuce crop under-shading was analysed. The results have shown that shading for this crop has no significant effect on the yield due to the adaptive capabilities of lettuce to adjust to the shading caused by the PV arrays. Thus, the same area of land was used to produce both, electricity, and food successfully [9-10]. Dupraz et. Al. was then able to prove that the yields from the agrivoltaic farm experiment were higher than their respective mono system equivalent with the use of the LER methodology. LER (Land Equivalent ratio: It is used to evaluate land utilisation efficiency in mixed cropping with respect to sole crops like LER = (((crop yield of agrivoltaic farm)/ (crop yield of sole crop farm)) +((electricity produced from agrivoltaic farm) +(electricity from regular PV plant))) is used to measure the efficacy of the agrivoltaic system when compared against a mono crop system [11]. Similarly, the LER for the PV output is obtained by comparing the power output of the agrivoltaic system against a standard PV farm. The LER for the solar power output is obtained by taking the ratio of the agrivoltaic system PV output and that of a regular PV farm. One of the primary factors that influence the output of both the PV modules and crop yield is shading, which is not necessarily always negative effect on the crop yield. In addition to shading, the crop output also depends on the photosynthesis process of the crops

in converting the incoming solar radiation into biomass [12]. It is difficult to predict the manner in which each plant behaves under shading [13] as shade tolerance of plant depends on the type of foliage and there appears to be co-relation between the leaf structure and plant tolerance to environmental conditions [14]. For example, lettuce can adapt itself to shading by increasing its leaf area to maximize its ability to tap the reduced solar radiation levels without significantly affecting yields, whereas shading causes a reduction in wheat yields as it cannot adapt to the reduced light conditions, experiments conducted on the Paulownias variety wheat grown under shade showed a reduction in wheat yield by 51% [15]. Some of the experimentally verified shade tolerant crops are less common in conventional mass agriculture such as hog peanut, alfalfa [16] yam, taro, cassava, and sweet potato [17]. For a plant in the understory, the attenuation of light by an overhead plant canopy can be profound force in natural selection [18]. The well-known designation, shade tolerant and sun tolerant have been applied to species that represents the two extremes of this selection [19], species in each group are photo synthetically inefficient in the light regime in which the other group evolved or acclimated. Most species however display an intermediate condition means they can acclimate photo synthetically to a range of light conditions through phenotypic plasticity, although the degree of this acclimation varies widely [20]. Morphological, as well as physiological acclimation to shade is common. In response to shading, plant generally reproduce less dry matter, allocate more of their resources to shoot production, and have greater specific leaf area, responses that result in overall increase in photosynthetic area [21]. Species with morphological plasticity may be able to maintain comparable relative growth rates over a broad range of light intensities [22]. The ability to acclimate to changes in light is undoubtedly important in explaining the ecological distribution of many species Shade-plants essentially follow strategies of optimum use of available energy and of conservation of energy. Adaptations to achieve these strategic goals include thinner leaves with a relatively higher chlorophyll content per unit leaf volume; lens-shaped epidermal cells that focus incoming light into and within the mesophyll red abaxial cell layer that reflects outgoing light back into the mesophyll; the greater allocation of available energy to defence-mechanisms against herbivory (as opposed to replacement of damaged tissue)—including camouflaging strategies such as mottled leaves; a distichous phyllotaxis; and flowers and fruit that are inconspicuous in size and colour. Plants that grow

best in full sunlight are called heliophytes; while sciophytes are those that grow best at lower light intensities. Obligate and facultative plants occur in both groups, with the facultative plants showing much variation in their degree of plasticity. True shade plants are obligate sciophytes and cannot tolerate full sunlight at all [23]. Stress-tolerance and stress-avoidance are the major strategies employed by living organisms to cope with environmental variation and extremities. Species that are stress tolerant occupy habitats of low productivity and limited resources. This holds true for shade plants. Survival in a shaded under storey demands maximization of light capture for photosynthesis with concurrent minimization of losses of energy and carbon. Plasticity in shade tolerance is expressed primarily during vegetative growth. The leaves and other organs of shade-growing species are long-lived and exhibit less plasticity in size and shape than do sun-growing species. The degree of plasticity shown by any plant species is regarded as being under genetic control and is an important characteristic determining the potential for survival of a plant under shaded conditions [24]. Plastic responses, which essentially depend on changes in gene expression and protein function, are continuously implemented in the plant, and serve several functions including the maintenance of metabolic homeostasis and foraging for resources and defence. In most cases, plastic responses involve metabolic as well as morphological and developmental components [25]. In assessing the value of the light factor, it must not be overlooked that photosynthesis is not the only function with a light-requirement. Phototropism, photoperiodism, photomorphogenesis (stem extension and apical dominance), seed germination, stomatal aperture, chloroplast orientation, and nastic (sleep) movements are all physiological manifestations of environmental light perception mechanisms [26]

High photosynthetic plasticity in certain lianas of tropical forest canopies is reflected in their almost immediate ability to respond to significant changes in the light environment. Rapid responses to light changes include functional adjustment of already expanded foliage and increases in leaf production in places with a large potential for carbon gain (27). Generally, “sun leaves” are relatively thick and have a well-developed palisade layer with a high proportion of columnar cells. “Shade leaves” on the other hand, are thinner, have a more poorly defined palisade layer, better developed sponge mesophyll, larger intercellular spaces, and a higher chlorophyll content per unit leaf volume than “sun leaves”. A common feature of plants that live in deep shade is the dark green colour of the foliage. This is

because of the increase of chlorophyll *b*, which results in a lower chlorophyll *a* to chlorophyll *b* ratio. As chlorophyll is purely a light harvesting pigment, this increase means that there is a higher proportion of light harvesting chlorophyll in the chloroplasts of shade-tolerant plants [28]. Insufficient light represses flowering and fruiting and sometimes holds vascular plants indefinitely in the vegetative condition. Low light intensity favours vegetative development at the expense of flowering and fruiting. Leaves tend to be borne in a spiral phyllotaxis in erect twigs in sunny environments and in a distichous (two vertical rows on opposite sides of an axis) phyllotaxis on horizontal twigs in the shade. This last arrangement minimizes self-shading and structural costs [29]. The explanation of differences between successful heliophytes and successful sciophytes is complex. Factors such as humidity, temperature, and minerals can vary greatly along with light intensity, and it is therefore difficult to evaluate light effects in isolation. Adaptation to the irradiance level at leaf-level alone does not explain shade plant behaviour satisfactorily. A holistic perspective is therefore important.

In an agrivoltaic system, the solar power output is maximized by optimizing the tilt angle to trap maximum solar radiation. The optimal tilt angle for the PV modules is normally based on the annual local solar irradiation [30]. Inter-row shading of the PV modules should be minimized, which is generally not a problem in agrivoltaics as the inter-row spacing tends to be larger than a conventional solar farm. The output of the PV module also depends on the operating temperature of a PV module, which is dependent on the ambient temperature, wind speed and solar radiation [31]. The crops in an agrivoltaic setup may improve the temperature of the PV array. On the other hand, the growth of plants between PV rows can have a negative effect due to dust generation from farming as dust collection on the PV modules decreases the electricity output. The amount of dust collected on the surface of the PV module decreases as the tilt angle increases [32]. Incorporating PV into agriculture can also be beneficial for crops. The shading caused by the PV modules helps in alleviating water evaporation during the summers and proves beneficial especially in the dry season.

All this process needed a proper designing of a solar power plant in both mechanical and electrical aspects. The crop selection, mounting height, optimal tilt angle, solar irradiation and local climate play a role in the optimal selection of PV system geometry for an Agri voltaic system. The configuration for the PV is determined by formulating an optimization problem with the objective of maximizing the

solar irradiation incident on the PV which in turn is proportional to the power output of the PV module while considering the addition all and cost from minimizing inter-row shading. The effect of this variances included in the objective function on the optimization problem [33]. To compensate for shading and its effect on crop yields, the PV density can be reduced or using semi-transparent panels having a radiation transmission rate of 50% or more [34]. The structural design for such solar farms has height at which the solar panels should be mounted and the tilt angle. It is because at higher altitude several environmental factors start playing their role mainly wind because the wind may result in several wind load effect on the structure. There are several software available to design the mechanical structure like Solid works and such simulations can also be done easily in these types of software. To increase the efficiency of the solar farm, tracking solar systems can be installed and this may result in moving shadow on the agricultural land. The effect of this shadow on crops needs to be studied. The electrical aspects of the solar farm consist of several factors like type of solar panels (monocrystalline solar panels, poly crystalline solar panels, thin film solar panels) due to the difference in their efficiency, use of inverters, batteries and the whether the solar farm will be supplying power to the fields and any domestic applications or will also supply the power to the grid. The main objective in designing a Solar Power Plant is to meet the load requirements of the consumer, at a minimum cost of the system. To accomplish this, the following data is required: Power Requirements, Solar irradiation Availability, Type and Size of Solar Power Plant Required, Cost of Energy Produced, Solar Power Viability, System Characteristics, System Requirement, Evaluation Criteria, Design Optimization, Economic Viability and Prospects of Cost Reduction [35]. Two major components used in solar power plants are Solar PV Panel, Power Conditioning Unit/grid tie inverter, Utility Grid/Grid System, and minor components such as DC array junction box, AC bus bar (LT and HT Switch gear), Control room, Cables, mounting structures, Earthing, and lightening, SCADA (Supervisory control and data accusation system), Water facilities/compound and fencing system and also roads inside the solar forms.

Need of the Study

This study is needed to find out the success rate of combining the agricultural land with the solar electricity generation farm because one of the major challenges in the instalment of solar farms is the

availability of Land. Solar energy installations are directly linked to land. The large-scale utility projects require vast amounts of land. MNRE has stipulated and prioritized the use of barren and waste lands for setting up of solar plants to not compromise on agriculture land. Also, land area requirement can vary depending upon the technology in use, whereby a decrease in land requirement can be achieved with greater efficiency in technology. As a key input, high land costs and bottlenecks in acquisition of land are important issues that require innovative policies. This Study is also needed to find out the contribution of solar electricity generation farm in the upliftment of farmer because agriculture is where solar power can prove to be largely inclusive. It can help irrigate farmers' fields, build cold storages in rural areas, and augment farmers' incomes by feeding the surplus power generated into the grid. Harvesting solar power on farmers' fields can thus act as harvesting another crop and can provide a sort of insurance even when rains fail.

Objectives of the Study:

1. Design of a multiple land use structure for mounting solar panels for power generation.

2. Designing Electrical network for receiving optimum solar power from the farm without affecting the crop.

3 Study of Business Models to combine solar electricity generation with the agriculture.

4 Study the Social acceptance of the model of combining solar electricity generation and Agriculture on the same land and can be called as Agri-Voltaic model.

Conceptual Framework of the Study

1. Select the piece of the land and designing of mechanical structure of solar panel supporting structure.

2. Decide the number of units needed to be installed in the farm as per the requirement of the total output power needed.

3. Electrical circuit designing for the whole farm.

4. Select the crops to be grown in the farm to get maximum yields.

5. Study the crop yield and the power generated from the farm.

Hypothesis of the Study

The following hypothesis is formulated for the proposed research. It is hypothesised that if such a crop is selected which is adapted to shade, then there will not be any negative effect on crop yield due to the shade of the Solar Panels Installed in the same field and also there will not be any adverse effect on the electricity generation from the Solar panels due to the crop grown in the same field.

Research Methodology

The proposed research will be quantitative and descriptive in nature as it will include surveys, categorization, and identification of patterns of the crops grown in the Solar agriculture farm. It will also follow the analytical method in the designing and analysis of suitable structure for mounting Solar Panels in the farm.

References:

[1] Mohammad Vahedi, Torshizi, Atefeh Hosseini Mighani. The Application of Solar Energy in Agricultural Systems Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Journal of Renewable Energy and Sustainable Development (RESD) Volume 3 Issue 2, June 2017 - ISSN 2356-8569

[2] Nonhebel S.Renewable energy and food supply: will there be enough land? Renew Sustain Energy Rev 2005; 9(2):191–201.

[3] CalvertK, PearceJM, MabeeWE. Toward renewable energy geo-information infrastructures:applications of GI Science and remote sensing that can build institutional capacity. Renew Sustain Energy Rev2013:18:416–29.

[4] CalvertK, MabeeW. More solar farms or more bioenergy crops? Mapping and assessing potential and-use conflicts among renewable energy technologies in eastern Ontario,Canada. ApplGeogr2015:56:209–21.

[5]Harshavardhan Dinesh, Joshua M. Pearce . The potential of agrivoltaic systems, Renewable and Sustainable Energy Reviews 2016: 54 :299-308

[6] Pearce JM. Photovoltaics–A path to sustainable futures. Futures 2002:34: 7:663–74.

[7] Barker PP, Bing JM. Advances in solar photovoltaic technology an applications perspective. IEEE Power Eng Soc Gen Meet 2005: 2 :1955–60.

[8] IEA. Technology Road map: Solar Photovoltaic Energy 2014.

[9]Marrou H, Wery J, Dufour L, Dupraz C . Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. EurJ Agron 2013:44:54–66.

[10]MarrouH, GuilioniL, DufourL, DuprazC, WeryJ. Microclimate under agrivoltaic systems:is crop growth rate affected in the partial shade of solar panels. Agric For Meteorol2013:177:117–32.

[11] Dupraz C, Marrou H, Talbot G, Dufour L, Nogier A, Ferard Y. Combining solar photovoltaic panels and food crops for optimising land use: towards new agrivoltaic schemes. Renew Energy 2011:36:10:2725–32.

[12] Zhu XG, Long SP, Ort DR. What is the maximum efficiency with which photosynthesis can convert solar energy into biomass. CurrOpin Biotechnol Food Biotechno /PlantBiotechnol 2008:19:2:153–9.

[13] Dupraz C, Talbot G ,Marrou H ,Wery J ,Roux S ,Liagre F ,Ferard Y ,Nogier A .To mix or not to mix :evidences for the unexpected high productivity of new complex agrivoltaic and agro forestry systems .In :Proceedings of the 5th World Congress of Conservation Agriculture .Resilient Food Systems for a changing world 2011 .

[14] Hallik L, Niinemets U, Wright IJ. Are species shade and drought tolerance reflected in leaf-level structural and functional differentiation in northern hemisphere temperate woody flora. New Phytol 2009: 184:1:257–74.

[15] LiF, MengP,FuD,WangB.Lightdistribution,photosyntheticrateandyieldin a paulownia-wheatintercroppingsysteminChina.AgroforSyst2008;74 (2):163–72.

[16] Lin CH, McGraw RL, George MF, Garrett HE. Shade effects on forage crops with potential in temperate agro forestry practices. Agro for Syst 1998: 44 :2–3 :109– 19.

[17] Johnston M, Onwueme IC. Effect of shade of photosynthetic pigments in the tropical root crops: yam, taro, tannia, cassava and sweet potato. Exp Agric 1998: 34:3:301–12.

[18] Harper JL Population Biology of Plants. Academic Press, London 1977

[19] Mehleri ED, Zervas PL, Sarimveis H, Palyvos JA, Markatos NC. Determination of the optimal tilt angle and orientation for solar photovoltaic arrays. Renew Energy 2010:35:11:2468–75.

[20] Bjorkman O, Holmgren. Adaptability of photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitat. Physiol Plant 16:889-914

[21] Boardman NK. Comparative photosynthesis of shade and plants. Annu Rev Plant Physiol 28: 355-377

[22] Grime JP, John Wiley. Plant strategies and vegetation process. New York 1979

[23] Peterson DL, Bazzaz FA. Life cycle characteristics of Aster pilosus in early successional habitat. Ecology 59: 1005-1013

[24] Daubenmire R. F. Plants and Environment 3rd ed. John Wiley & Sons Inc. U. S.A 1974.

[25] Dengler N.G. The influence of light on leaf development. In. Growth patterns in vascular plants. Dioscorides Press Oregon 1994.

[26] Aphalo PJ, Ballaré CL , Scopel AL. Plant-plant signalling the shade avoidance response and competition. J Exp Bot 1999:50.

[27] Morgan DC, Smith H. Non-photosynthetic responses to light quality. Encyclopaedia of plant physiology. Springer Verlag Berlin 1981: 12A: 109:130

[28] Avalos G., Mulkey S.S. Photosynthetic acclimation of the liana Stigma phyllon Lindenbaum light changes in a tropical dry forest canopy. Oecologia 1999:20: 475–484.

[29] Crawford R.M.M. Studies in plant survival. Ecological case histories of plant adaptation to adversity. Blackwell Scientific Publications Oxford :1989

[30] Givnish TJ, J Theor Biol. Biomechanical constraints on self-thinning in plant populations. 1986*:* 119: 139−146.

[31] Skoplaki E, Palyvos JA. Operating temperature of photovoltaic modules. A survey of pertinent correlations.Renew Energy 2009 :34 :1 : 23–9.

[32] Talbot G, Roux S, Graves A, Dupraz C, Marrou H, Wery J.Relative yield decomposition a method for understanding the behaviour of complex crop models. Environ Model Softw 2014:51:136–48.

[33] Mehleri ED, Zervas PL, Sarimveis H, Palyvos JA, Markatos NC. Determination of the optimal tilt angle and orientation for solar photovoltaic arrays. Renew Energy 2010:35:11:2468–75.

[34] Wong PW, Shimoda Y, Nonaka M, Inoue M, Mizuno. Semi-transparent PV thermal performance, power generation, day light modelling and energy saving potential in a residential application.Renew Energy 2008:33 :5:1024–36.

[35] Vasanth kumar, Dr. S. Kumarappa, Dr. H. Naganagouda.Design and Development of 5MW Solar PV Grid Connected Power Plant Using PVsyst.International Research Journal of Engineering and Technology 2017.